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ASSESSMENT OF THE WATER QUALITY OF VALENS LAKE AND THE EFFECTIVENESS OF ARTIFICIALLY-INDUCED DESTRATIFICATION

Ministry of the Environment

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ASSESSMENT OF THE WATER QUALITY
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Table of Contents

List of Tables and Figures

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I am particularly grateful to W. Kennedy, P.J. Dillon, and I. Wile who provided valuable comments and criticisms of the manuscript.

ABSTRACT

The water quality of an impoundment formed in 1966 by the damming of a small creek was evaluated on the basis of various physical, biological, and chemical parameters. Particular emphasis has been given to dissolved oxygen, water clarity, chlorophyll a, and the inorganic plant nutrients.

A flourishing macrophyte community has been developing since the lake's formation. At present, the entire lake bottom is covered with macrophytes, detracting greatly from recreational use.

Aeration of the reservoir since 1972 has not conclusively ameliorated water quality problems, but since the lake was poorly characterized prior to aeration, a good assessment of the effects of the induced circulation is difficult to make. It is felt that rapid community succession and associated environmental changes may be obscuring any effects of the artificial mixing.

INTRODUCTION

Valens Lake was formed in 1966 when the Hamilton Region Conservation Authority (H.R.C.A.) dammed the west branch of Spencer Creek immediately north of Highway 97 in Beverly Township, Wentworth County, approximately 15 kilometres east of Cambridge, Ontario. In the spring of 1972, the dam was converted from a bottom draw to an overflow type.

The lake was originally designated for the dual purposes of summer flow augmentation and flood control (MacBeth et al.,1973), but since its formation, these have been subordinated by the recreational activities of swimming, boating (power boating is prohibited) and fishing.

The shallow nature of Valens Lake provides an ideal habitat for aquatic macrophytes, specifically *Myriophyllum* sp., *Elodea* sp., *Chara* sp. and *Potamogeton* spp. which abound throughout the lake. In 1972, *Myriophyllum* sp. was the most conspicuous of these. Plant growth was curtailed in the swimming area with some success by the use of the herbicide diquat and some limited mechanical weed harvesting.

Since 1974, the swimming area has been isolated by a plastic barrier to facilitate control of swimmer's itch (schistome dermatitis) by chlorination of the enclosed water. This skin infection is caused by the larvae of a trematode that normally infects water fowl. Excessive weed growth provides plentiful food and substrate for snails which are the intermediate hosts of the parasite. Thus, the large plant biomass may be an important indirect cause of this problem. Isolation and chlorination of the area has the additional benefit of controlling macrophyte growth along the beach.

In late summer of 1971, an *Aphanizomenon* bloom was followed by the appearance of an oxygen depletion in the deeper water, suggesting chemical stratification of the lake. The following winter, the Ministry of the Environment (MOE) recommended the implementation of artificially-induced destratification to restore oxygen to the bottom stratum. Many studies have proven that aeration is capable of increasing oxygen concentrations in bottom waters (Bernhardt, 1967; Fast, 1973; Fast and Amant, 1971; Koberg and Ford, 1965; etc.).

The oxygen shortage was accompanied by a strong odour of hydrogen sulphide in the discharge water at the bottom of the dam. This noxious gas is produced by sulphate-reducing anaerobic bacteria, and the restoration of oxygen prevents further release of the gas. Hydrogen sulphide levels fall at the onset of aeration although sulphate concentrations generally show little or no change (Fast, 1968; Symons et al.,1968). It is thought that H_2S is vented at the surface before any significant oxidation to sulphate occurs (Leach and Harlin, 1970).

It was believed that the increased oxygen levels would benefit the lake by reducing phosphorus concentrations through precipitation to the sediments in combination with oxidized forms of iron and manganese. This reduction has been observed by other workers (Björk, 1974; Wirth and Dunst, 1967). In the absence of free oxygen, species of Fe and Mn become reduced and soluble, releasing phosphorus into solution. However, the predictability of the response of phosphorus to aeration is not simple. Schindler (1975) has observed phosphorus retention by lake sediments under both oxic and anoxic conditions. Such inconsistencies preclude the drawing of definite conclusions concerning the overall biogeochemistry of this important element.

Nitrogen, the other important inorganic plant nutrient, is also affected by destratification. The clinograde distribution of ammonia is disrupted as it becomes oxidized to nitrite and subsequently nitrate (nitrification) or is vented at the surface (Björk, 1974; Lee, 1970; Wirth and Dunst, 1967). Brezonik et al.,(1969) speculated that after aeration, the sediments act as a sink for particulate nitrogen which settles from the water column. The significance of nitrogen removal in eutrophication control is unclear because nitrogen is usually not limiting to primary production in north temperate lakes and because many of the Cyanophyta obtain the biologically useful combined forms of nitrogen by conversion of elemental nitrogen gas to nitrate.

STUDY AREA

Valens Lake drains 11 km^2 and itself covers an area of 61 ha. The lake is shallow (maximum depth 4.6 m) with a volume of 12 x 10^5 m^3 (MacBeth et al.,1973). During summer, the rate of flow is low with an estimated 0.02 to 0.03 m^3/sec passing over the dam.

The northern portion of the lake (see Figure 1) is very shallow with a few small islands, while the lower section (of about 32 ha.) is deeper with more open water. Mayall (1965) describes the flooded area as swamp and pastureland of neutral to alkaline soil covering Silurian dolomite of the Guelph Formation. No topsoil was removed prior to inundation. Approximately seventy-five percent of the drainage basin is occupied by the Galt Moraine and characteristic drumlin and hummocky topography dominate this region of sandy till. Immediately to the east and west of the lake are areas of dolomite outcrops. Peat and muck deposits cover a swampy region north of the reservoir (Ont. Dept. of Mines, 1963). Forty percent of the basin is wooded (mixed forest) with some swampy sections, the remainder being primarily used for pastureland with a smaller portion under intensive cultivation.

METHODS

Artificially-induced destratification was commenced on June 26, 1972 using a 2 H.P., 0.28 m^3/min compressor pump connected by polyvinyl chloride tubing to a Y-shaped diffuser in the deepest part of the lake (see Figure 1). The pump has been in operation during the ice-free period until the present date. Since 1975, aeration has been restricted to the 8:00 p.m. to 8:00 a.m. period with the aid of an automatic timing device. Thus, energy and maintenance expenditures have been reduced while maintaining circulation at night when oxygen levels are most likely to drop.

Three sites were selected for sampling stations as shown in Figure 1. Station 1 is at the deepest point and is very close to the diffuser.

Station 2 is further from the diffuser and closer to the beach while station 3 is in shallow water in the upper part of the reservoir. These latter two stations are about two metres deep.

Surface samples were taken weekly in 1972 from June to November, weekly in 1973 from April to November, and monthly in 1975 from May to September. Samples from 3 m were also taken at station 1 and from 1.5 m at stations 2 and 3. Sampling was discontinued at station 2 in 1973 and the 1.5 m sampling depth was deleted from station 3 in 1975.

Background data were collected annually by the H.R.C.A. but only water from below the outfall was monitored. These data are not useful in assessing the effects of aeration because the dam discharge was changed from bottom draw to overflow shortly before the beginning of artificial mixing. Differences in H.R.C.A. and M.O.E. methods and measurements also preclude comparisons.

Water transparency was measured at each station using a Secchi disc. Temperatures were measured by thermometer and dissolved oxygen by the azide modification of the Winkler technique (American Public Health Association, 1971). Total and dissolved reactive phosphorus, ammonia, Kjeldahl nitrogen, nitrite, nitrate, iron, manganese, silica, conductance, and total chlorophyll *a* were analyzed as outlined by the American Public Health Association (1971). Carbon dioxide, pH, alkalinity, hardness, and chloride were determined at the H.R.C.A. lab in 1972 but in 1973 and 1975, all analyses were done by the Ministry of the Environment.

RESULTS AND DISCUSSION

A) Physical and Biological Parameters

1) Temperature

Water temperatures in Valens Lake vary seasonally from a summer peak of 26°C to near freezing below the surface ice in winter. The lake remains homeothermous with depth, the greatest measured temperature differential between the surface and 3 m being 2°C. According to

MacBeth _et al_ (1973), there was no evidence of thermal stratification before aeration so the induced circulation had little effect in this regard. Sufficient data are lacking to assess any changes in the heat budget of Valens Lake.

2) Secchi Disc Transparency and Chlorophyll _a_

In 1972, Secchi depths ranged from 0.5 m to 2.5 m with the lowest readings occurring during the September algal bloom. Data from 1973 indicate an improvement in water clarity with readings ranging from 1.3 m to greater than the maximum lake depth (4.3 m). The mean reading for the June to September recreational period was 2.5 m. Secchi depths were measured on only two dates in 1975, both readings being 2.5 m.

Surface total chlorophyll _a_ and Secchi disc values at station 1 in 1973 are plotted in Figure 2. Some degree of correlation was found between the two variables ($r = 0.65$) but other factors such as silt-laden storm run-off, resuspension of bottom sediments by wind action, the intensity of solar radiation, and the smoothness of the lake surface all influenced the Secchi disc readings. H.R.C.A. data indicate a range of suspended solids in the May-August period of 1974 of 4.0 to 30.4 mg/l with sporadic fluctuations largely independent of chlorophyll _a_ concentrations.

B) Chemical Parameters

1) Oxygen

Aeration has apparently been successful in achieving its prime objective - the maintenance of dissolved oxygen in the bottom waters of Valens Lake. However, problem-causing oxygen shortages could have occurred very close to the sediment interface, thereby escaping detection. Similarly community respiration, particularly by the macrophytes, could have caused shortages at night that would have gone unnoticed.

The development of near anoxia on September 29, 1972 has been ascribed to two events (MacBeth _et al_.,1973); the dying off and decay

of a dense algal bloom and a three-day compressor failure a few days earlier. No such reason can be found for the oxygen deficit found at 3 m on July 10, 1973 (Figure 3).

On September 12, 1972, a peak in dissolved oxygen in Valens Lake is attributable to the *Aphanizomenon* bloom (see Figure 4). Supersaturation has not since recurred to a comparable extent on any sampling date, in keeping with the failure of any phytoplankton population to attain bloom proportions.

It is not known whether aerobic conditions were maintained under the ice in winter when the pump was out of operation. Near saturation levels in the bottom waters just after ice break-up in April of 1973 (see Figure 3) suggest an adequate oxygen supply under winter ice cover.

2) Major Ions

Marl (calcium carbonate) is precipitated from solution by photosynthesis in hard waters. This removal from solution causes a decrease in conductance. From 1967 to 1971, conductivity decreases in summer became progressively greater each year as more marl was precipitated by the expanding plant populations. It can be seen from Figure 5 that in 1975, the decrease in conductance was about 40% of the spring peak, representing much photosynthetic activity in the lake.

Although hardness data are not available for 1973, Ca^{++} concentrations declined from a spring high of 50 mg/l to an August low of 29 mg/l (as Ca), while alkalinity fell from 188 to 148 mg $CaCO_3$/l. In 1975, surface hardness dropped from 214 to 125 mg/l and alkalinity from 174 to 105 mg/l between May 14 and August 18.

3) CO_2 and pH

As carbon dioxide is fixed into organic compounds by autotrophic plants, pH rises and marl precipitates from solution. In 1972, pH ranged from 7.5 at the beginning of October following the algae bloom to summer maxima of 9.6. The following year, surface pH ranged from 8.1 to 8.7 between April and November. Throughout the June to August

period, levels were generally above 8.5. In 1975, pH increased from 8.1 in spring to 9.1 in summer. Depth and horizontal position seemed to have little bearing on pH. Diurnal pH variability caused by net CO_2 uptake or release was not determined.

Carbon dioxide was measured only in 1973 when it was found to be generally absent from all depths and stations between late May to late August. In spring, CO_2 ranged from 0 to 3.1 mg/l but by late May, photosynthetic activity was apparently great enough to deplete free CO_2 during daylight hours. However, on two occasions CO_2 was found at a 3 m depth at levels up to 8 mg/l. On another date, CO_2 was found to be present throughout the water column at station 3. Each of these days was characterized by cloudy skies, probably resulting in reduced photosynthetic activity. The September accumulation of CO_2 likely resulted from the decay of plant material.

4) Iron and Manganese

Prior to aeration, iron concentrations in Valens Lake ranged between 0.25 and 0.45 mg/l. Following the onset of aeration, iron levels declined to even lower levels of 0.10 to 0.20 mg/l. On September 29, 1972, a peak of 0.85 mg/l was found at the 3 m depth, corresponding to an oxygen minimum. Iron concentrations ranged from 0.10 to 0.35 mg/l in 1973 with the lowest levels appearing in May and June and the highest in July. On occasion, iron levels were higher at 3 m than in surface water, suggesting a low redox potential near the bottom. The highest concentrations generally coincided with the lowest dissolved oxygen levels. In 1975, iron ranged from 0.10 to 0.68 mg/l and on three of the five sampling dates, higher concentrations were found in the bottom strata than in the surface waters.

Manganese was found at levels below the detection limit (0.04 mg/l) on four occasions in 1973 and at a maximum level of 0.32 mg/l on July 10. No seasonal pattern was readily perceptible. Values of 0.02 to 0.18 mg/l were obtained in 1975. This element was not analyzed in Valens Lake water in 1972. As was the case with iron, the highest manganese levels were coincident with the lowest oxygen concentrations.

5) Silica

In 1972, MacBeth *et al.*,(1973) found silica levels ranging from less than 2 mg/l to a peak of 6 mg/l (as SiO_2) with a gradual increase throughout the summer followed by a decline in November. It was also noted that silica was generally higher at station 3 than station 1. The following year, silica ranged in concentration from 0.10 to 9.8 mg/l. Again there was a gradual increase during the summer and station 3 tended to have higher levels than station 1. Homogeneity with depth was generally maintained. The scarcity of 1975 data makes it difficult to see any pattern. Higher concentrations at station 3 in 1972 and 1973 may be associated with warmer sediment temperature than at station 1 as explained below.

Yoshimura (1930) attributed the rise in silica throughout the summer to the lack of uptake of the nutrient by diatoms at this time of year coupled with a silica contribution made by sediments and inflowing water. According to Hutchinson (1957), should anaerobic conditions develop, the reduction of ferric silicate in the lake bed may release silica. There is also indication that silica tends to enter water from epilimnetic mud at high temperatures (Hutchinson, 1957).

6) Nitrogen

Ammonia and nitrate nitrogen levels remained low during the summers of 1972, 1973 and 1975 with ammonia-N concentrations ranging from less than 10 μg/l (detection limit) to 120 μg/l and nitrate-N from 6 μg/l to 10 μg/l in the surface water. From Table 1, it is evident that both forms of nitrogen increased in concentration in the fall. In September of 1972, NH_3-N reached 320 μg/l in the bottom water following the senescence of the blue-green algal bloom. The fall increase in 1973 was less dramatic but concentrations did peak at 140 μg/l. Peaks in ammonia levels of 320 μg/l on September 29, 1972 and 310 μg/l on July 10, 1973 both coincided with low oxygen levels in the bottom waters, probably reflecting high levels of microbial activity.

Kjeldahl nitrogen reflected phytoplankton biomass as indicated

by chlorophyll a. The 1972 peak of 3.9 mg N/l (at station 3) on September 12 was coincident with the peak in total chlorophyll a of 160 μg/l. The 1975 maximum of 1.2 mg/l occurred at the time when chlorophyll a reached its peak of 47 μg/l.

Aeration of Valens Lake may suppress NH_3 formation by maintaining oxygen in the deeper water, thereby favouring nitrification of NH_3 to nitrite and nitrate. The vertical distribution of nitrite and nitrate probably became more isochemical after aeration. Unfortunately conclusive evidence is lacking because of the absence of pre-aeration data.

7) Phosphorus

Total phosphorus levels fluctuated between 20 to 30 μg/l in the surface waters (see Figure 6 and Table 1) although higher levels (up to 71 μg/l) were measured in 1975. A similar range of concentrations supported extremely dense blooms of *Aphanizomenon*, *Anabaena*, and *Ceratium* in Heart Lake in 1976 (M.O.E. unpublished data).

Samples from bottom strata occasionally contained higher phosphorus concentrations than the surface waters, probably due to the settling and decomposition of organic matter and to dissolution from the sediment when oxygen levels were low. Higher phosphorus levels were found in the bottom waters at times when oxygen levels were deficient in Valens Lake in spite of aeration.

CONCLUSIONS

Valens Lake is a eutrophic body of water with much of the autotrophic biomass occurring in the macrophyte component. Macrophyte abundance is a reflection of the shallow depth, rich sediments, abundance of plant nutrients, and low flow rate. Chlorophyll a levels have remained relatively high and water transparency low, despite the preponderance of the macrophytes that compete with the phytoplankton. The only indication of improvement in water quality since the start of aeration is the failure of an algal bloom

of 1972 proportions to recur and an improvement in clarity since that year.

Any change in the status of Valens Lake may be largely a consequence of community succession. Due to the very recent formation of the lake, the ecosystem has only been developing for a short time. The first successful phototrophic invaders were probably "r-selecting*" algae, causing the preponderance of phytoplankton in earlier years. As succession proceeds to a climax community, more and more weeds will fill the lake and a lower, more stable production/biomass ratio is achieved. Perhaps a valuable ecological study has been overlooked.

Weed growth poses no serious problem to the use of Valens Lake for summer flow augmentation and flood control in the creek but conflicts with recreational purposes.

RECOMMENDATIONS

Weed harvesting and dredging would temporarily alleviate the macrophyte problem. Overwinter drawdown has been used with some success for reducing the extent of macrophyte growth in impoundments (Beard, 1973). Despite the present mid-October drawdown practices in Valens Lake, weeds continue to thrive. Earlier drawdowns would permit longer exposure and more complete drying of the lake bed perhaps resulting in a reduction in macrophyte growth.

To discover if the benefits of aeration in Valens Lake are real or imagined, short-term before and after oxygen measurements could be made with the pump off. If after several such tests no significant effect is found, then aeration should be terminated.

*A term first coined by MacArthur and Wilson (1967) to describe resilient species with high reproductive capacities.

REFERENCES

AMERICAN PUBLIC HEALTH ASSOCIATION. 1971. Standard Methods for the Examination of Water and Wastewater. 13th Ed. Washington, D.C.

BEARD, T.D. 1973. Overwinter drawdown - impact on the aquatic vegetation in Murphy Flowage, Wisconsin. Dept. Nat. Res., Madison, Wisconsin. Tech. Bull. No. 61.

BERNHARDT, H. 1967. Aeration of Wahnbach Reservoir without changing the temperature profile. J. A.W.W.A. 59:943-964.

BJÖRK, S. 1974. European lake rehabilitation activities. Plenary lecture at the Conference on Lake Protection and Management, Madison, Wisçonsin. Oct. 21-23, 1974.

BREZONIK, P., J. DELFINO, G.F. LEE. 1969. Chemistry of N and Mn in Cox Hollow Lake, Wisconsin, following destratification. J. Sanit. Eng. Div., A.S.C.E., 95(SA5):929-940.

FAST, A.W. 1968. Artificial destratification of El Capitan Reservoir by aeration. Part 1: Effects on chemical and physical parameters. Calif. Div. Fish Game, Fish. Bull. No. 141.

FAST, A.W. 1973. Effects of artificial hypolimnion aeration on rainbow trout (Salmo gairdneri, Richardson) depth distribution. Amer. Fish. Soc. 102:715-722.

FAST, A.W. and J.A. ST. AMANT. 1971. Nighttime artificial aeration of Puddingstone Reservoir, Los Angeles County, California. Calif. Fish and Game 57:213-216.

HUTCHINSON, G.E. 1957. A treatise on Limnology. Vol. 1. Wiley and Sons Inc., London, chap. 12, 14.

KOBERG, G.E. and M.E. FORD. 1965. Elimination of thermal stratification in reservoirs and resulting benefits - with special emphasis on study of Lake Wohlford, California. Geological survey water - supply paper 1809 - M. U.S. govt. print. off., Washington.

LEACH, L.E. and C.C. HARLIN. 1970. Induced aeration of small mountain lakes. Nat. Water Qual. Cont. Res. Prog., Region VI, Ada E.P.A., Wat. Qual. Off. Prog. No. 16080.

LEE, G.F. 1970. Factors affecting the transfer of material between water and sediments. Eutrophication Inform. Prog. Univ. Wisconsin. Occasional papers.

MacARTHUR, R.H. and E.A. WILSON. 1967. The Theory of Island Biogeography. Princeton Univ. Press, New Jersey.

MacBETH, S.E., T.G. BRYDGES, M.D. PALMER, and D.M. VEAL. 1973. Artificially induced destratification of Valens Lake - 1972. Ont. Ministry of the Environment, Water Resources Branch, Toronto, Ontario.

MAYALL, K.M. 1965. Report to the Hamilton Conservation Authority on conditions prior to the flooding of Valens Lake.

ONTARIO DEPARTMENT OF MINES. 1963. Map 2029 - Pleistocene Geology of the Galt Area.

SCHINDLER, D.W. 1975. Whole-lake eutrophication experiments with phosphorus, nitrogen, and carbon. Verh. Internat. Verein Limnol. 19:3221-3231.

SYMONS, J.M., W.H. IRWIN, G.G. ROBECK. 1968. Control of reservoir water quality by engineering methods. In Symons, J.M. (ed) Water quality behaviour in reservoirs: a compilation of published research papers. Publ. Health Serv. Publ. No. 1930. Cincinnati, Ohio. pp.335-390.

WIRTH, T.L. and R.C. DUNST. 1967. Limnological changes resulting from artificial destratification and aeration of an impoundment, Research Rep. No. 22. Wisconsin Conserv. Dept.

YOSHIMURA, S. 1930. Seasonal variation of silica in Takasuka-numa, Saitama. Jap. S. Geol. Geogr. 7:101-113.

Table 1 Mean* Monthly Nitrogen and Phosphorus Levels** in Valen's Lake 1972-1975

Surface at Station 1

Month	Year	Total Phosphorus	Dissolved Reactive Phosphorus	Total Kjeldahl-N	NH_3-N	NO_3-N	NO_2-N
April	1973	32	3	550	17	117	6
May	1973	36	4	750	65	18	4
	1975	18	4	600	100	20	9
June	1972	24	2	780	30	10	-
	1973	23	2	890	20	<10	4
	1975	22	2	550	10	20	4
July	1972	20	2	630	<10	<10	-
	1973	29	3	750	66	<10	3
	1975	40	2	760	<10	<10	2
August	1972	27	4	670	20	<10	-
	1973	26	7	715	30	<10	3
	1975	64	1	1200	20	<10	2
September	1972	58	13	1550	145	15	-
	1973	21	10	735	95	<10	4
	1975	56	19	1000	<10	<10	3
October	1972	44	10	1000	150	90	-
	1973	26	10	810	40	25	6
November	1972	40	14	1000	130	100	-
	1973	23	7	720	10	100	3
December	1972	35	4	1200	270	260	-

* Means of one to five determinations

** in µg/l

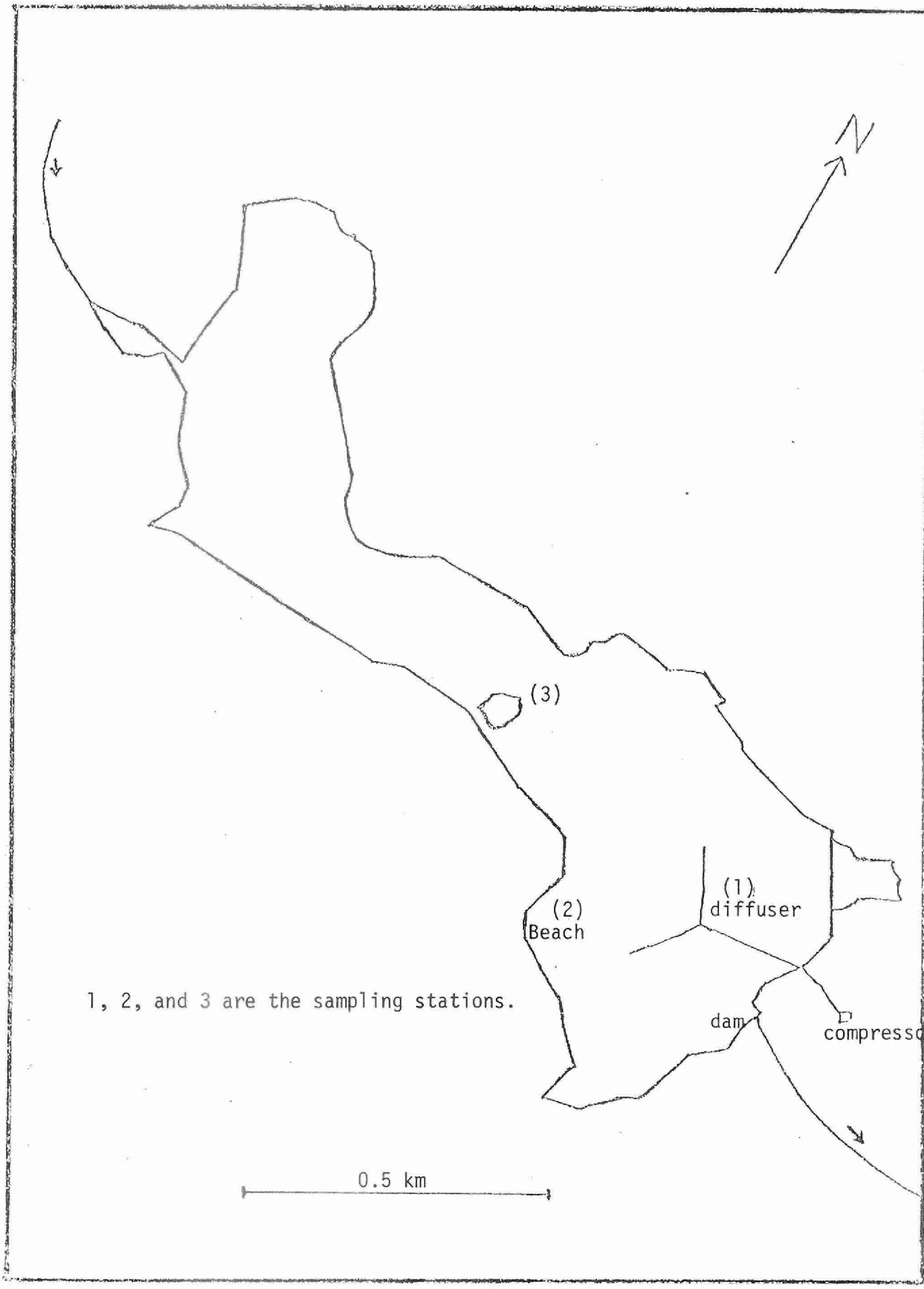

Figure 1 - Valens Lake

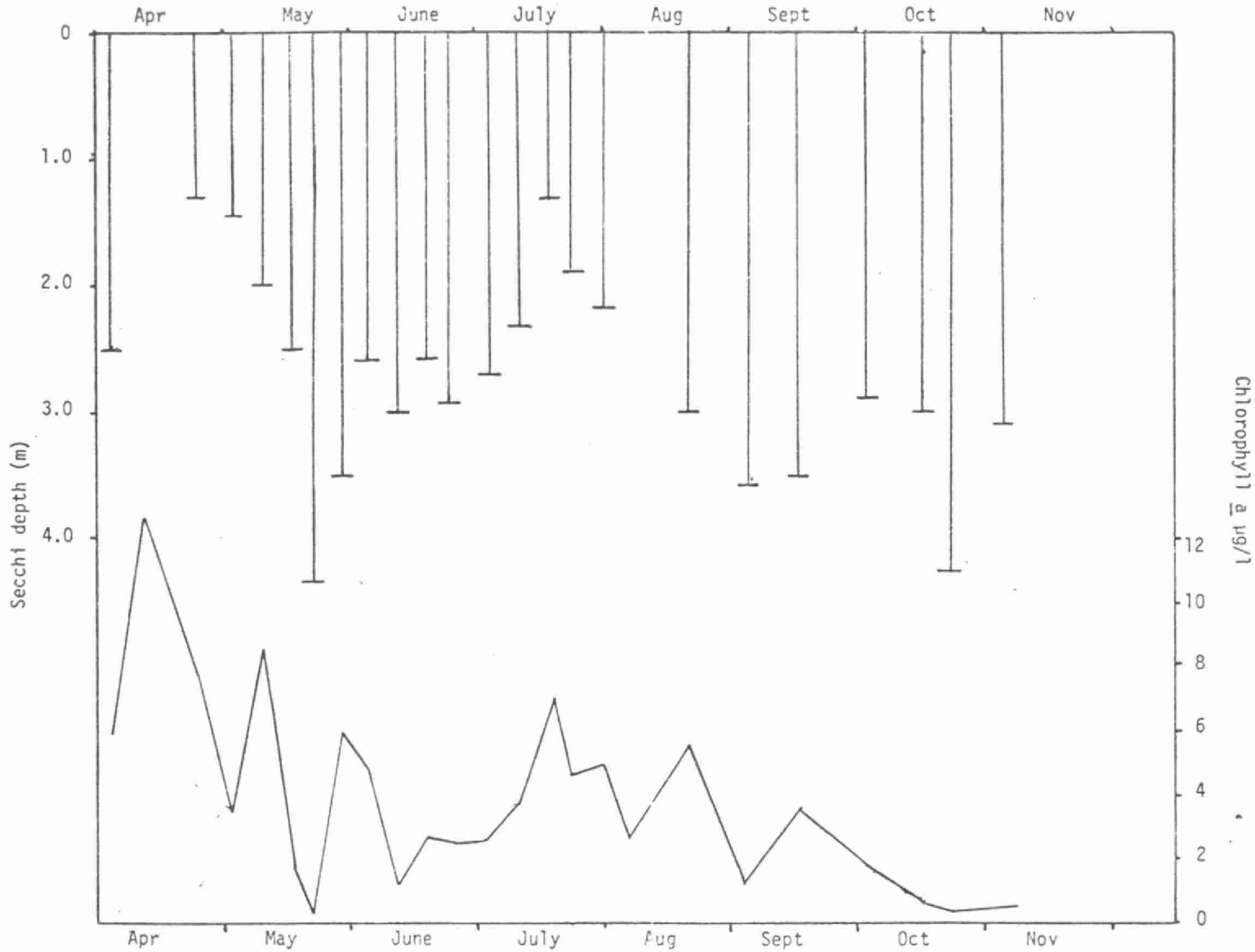

Figure 2 - Chlorophyll a and transparency at station 1 in 1973.

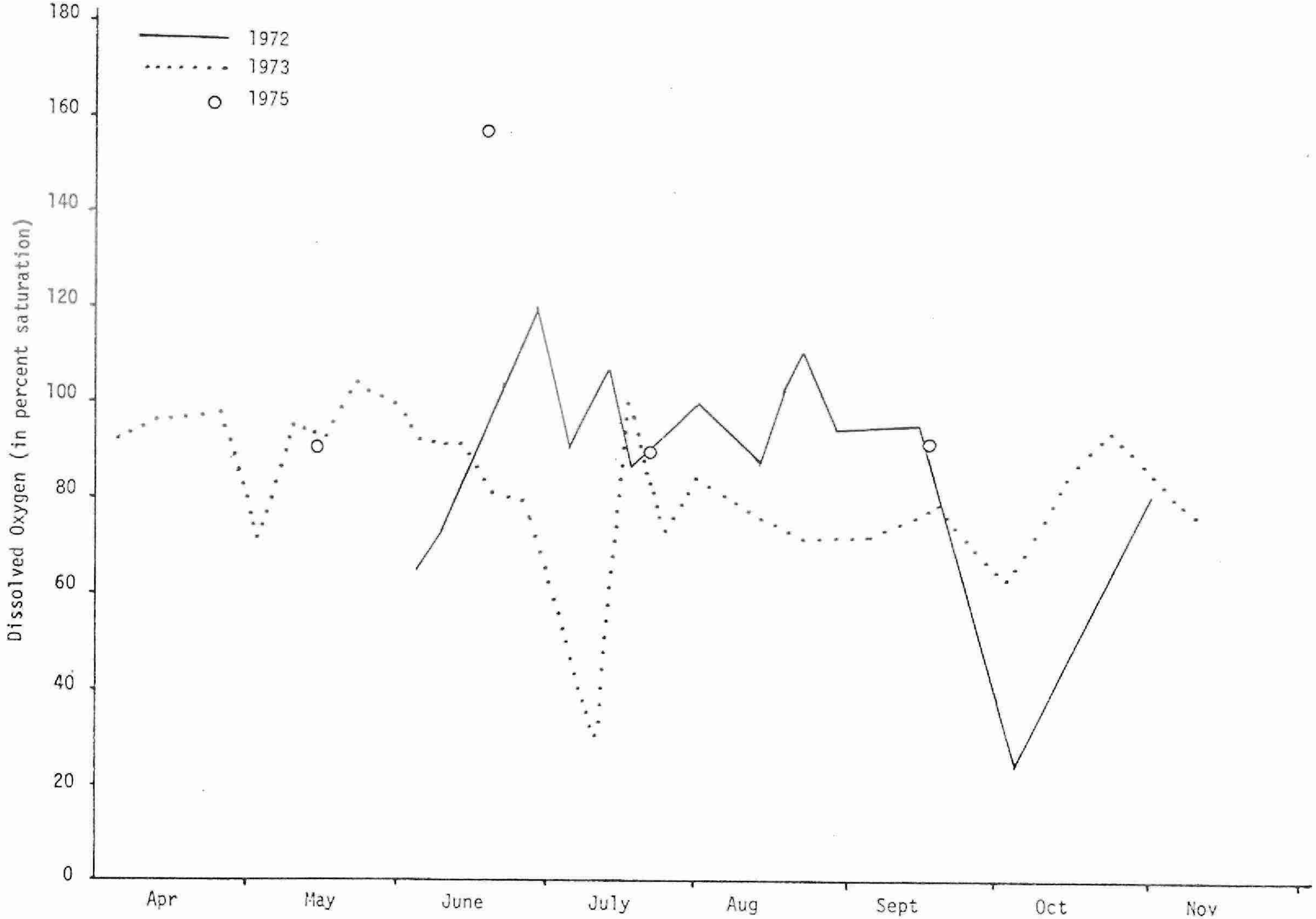

Figure 3 - Dissolved oxygen in bottom water (3m) at station 1.

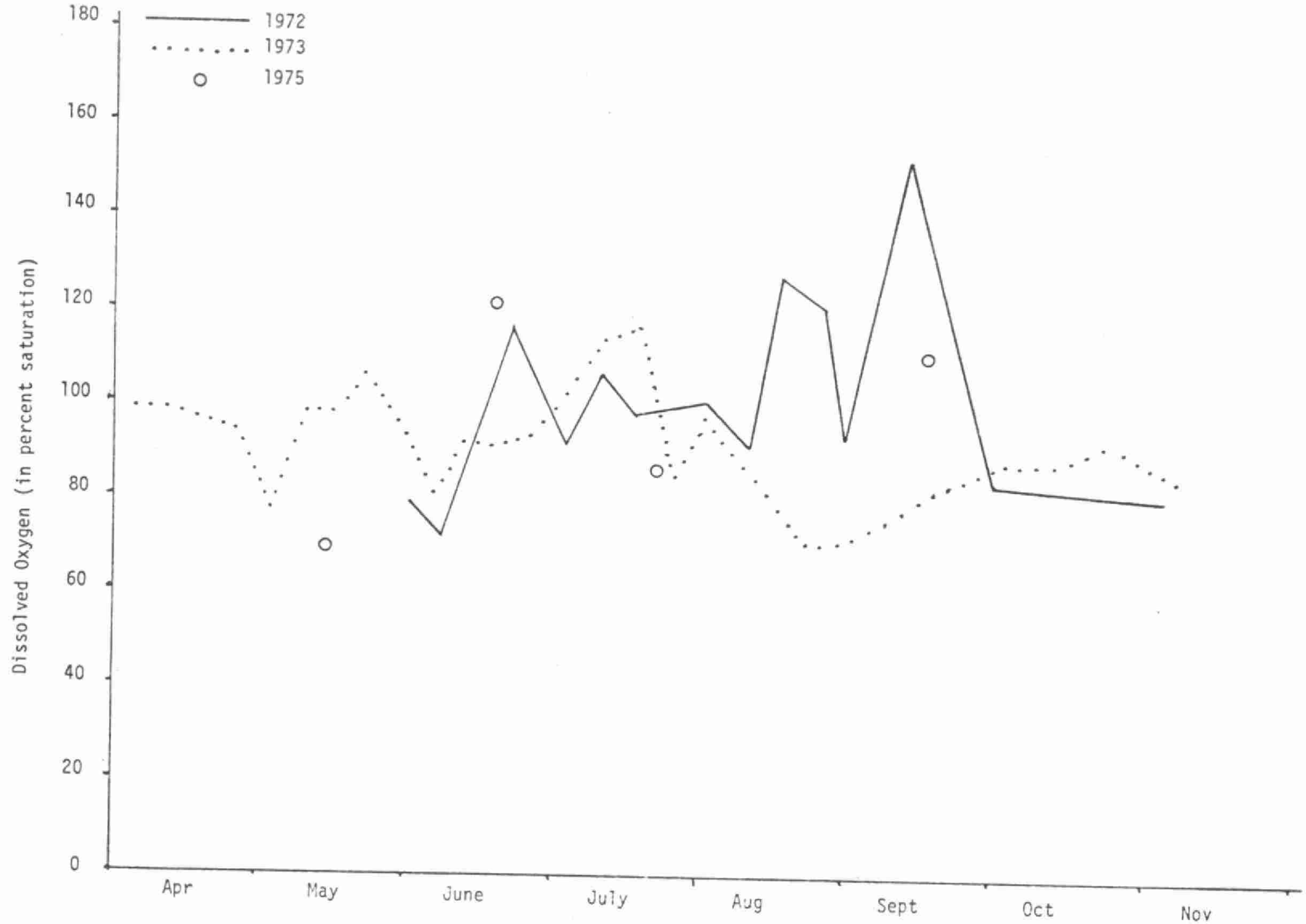

Figure 4 - Dissolved Oxygen in surface water at station 1.

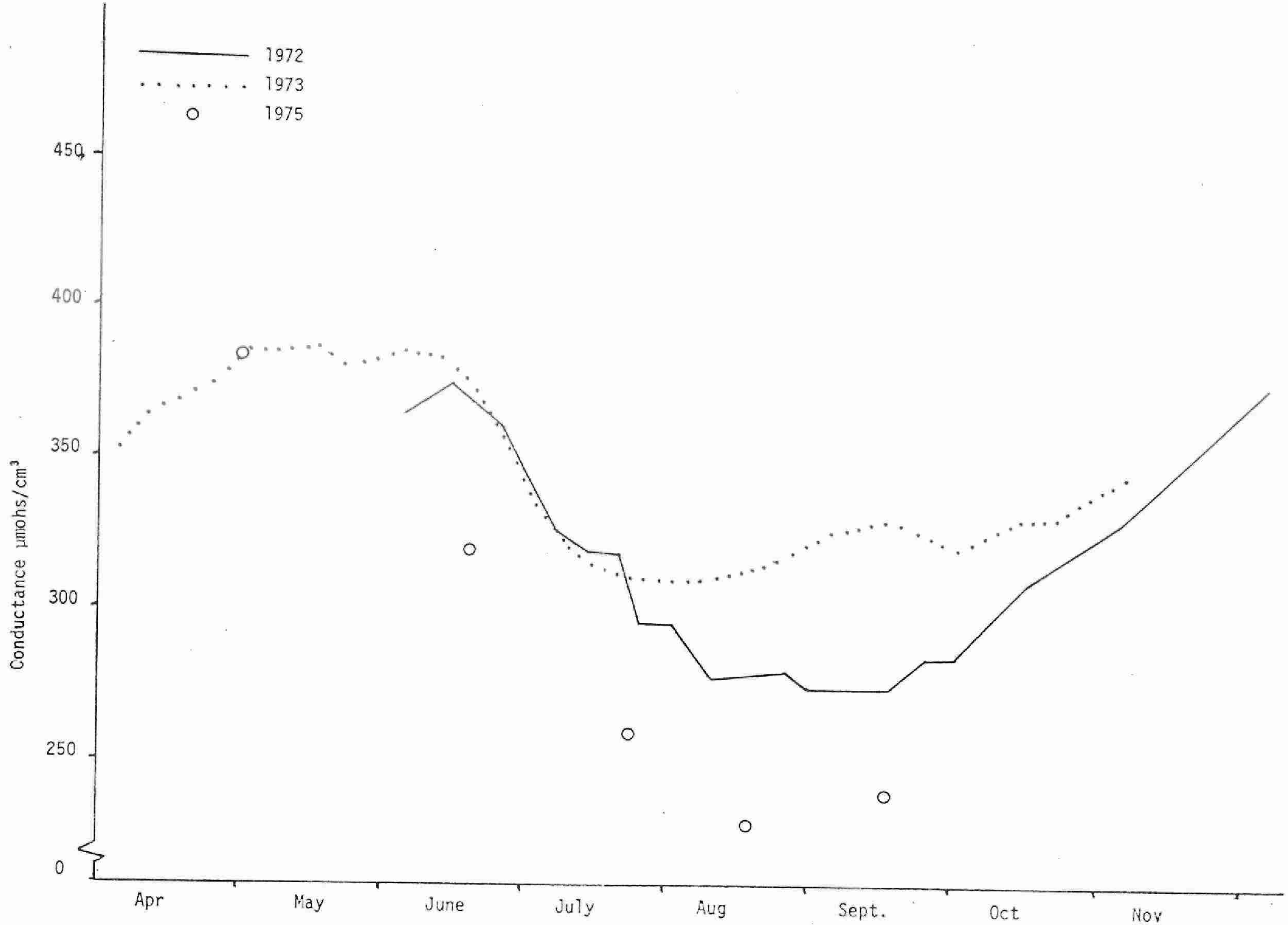

Figure 5 - Conductivity in surface water at statior 1.

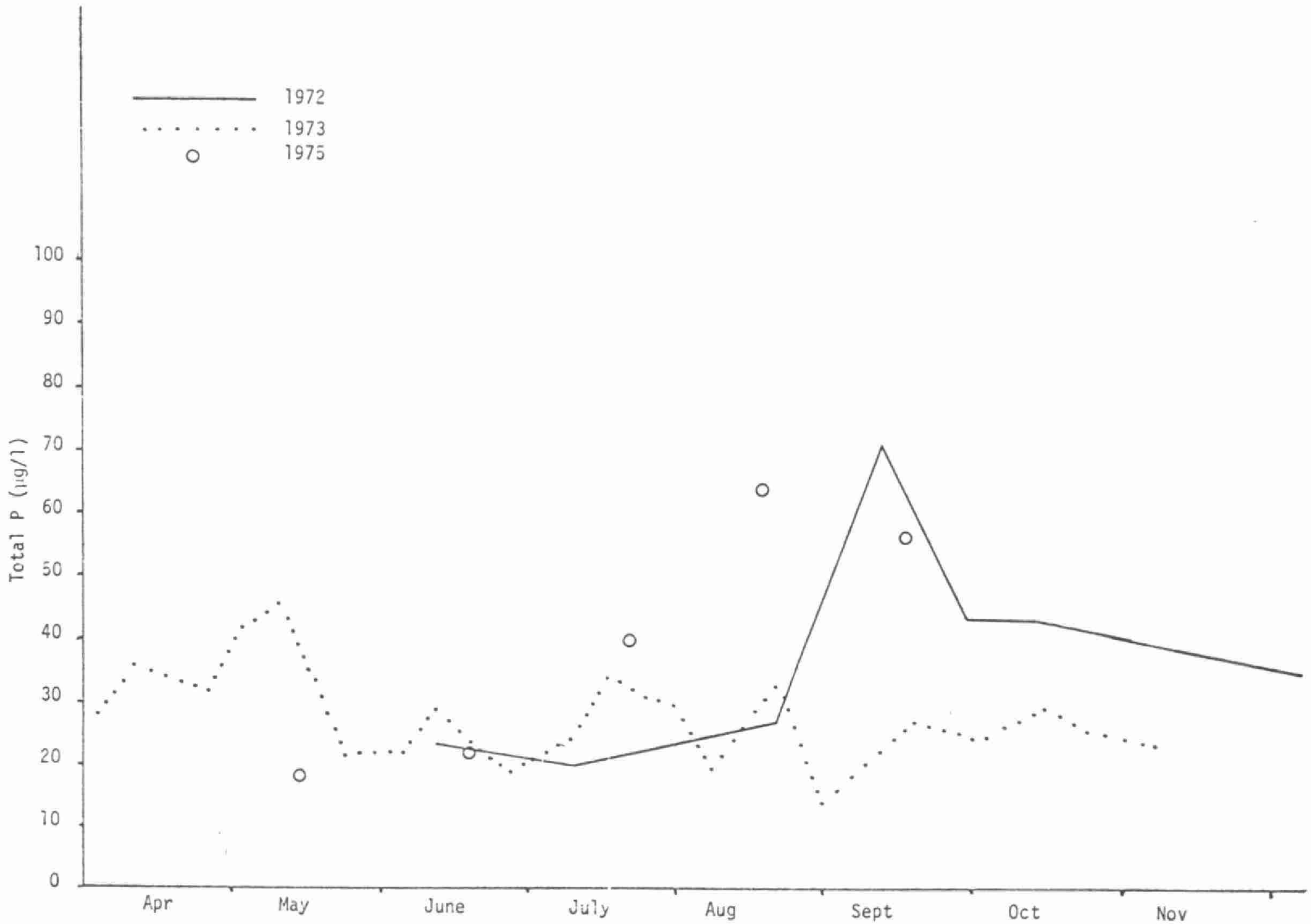

Figure 6 - Total phosphorus in surface water at station 1.